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Baseline

Rate of sediment accumulation and historic metal contamination in a tidewater glacier fjord, Svalbard

Mahesh Mohan[a,*], U. Sreelakshmi[a], M.K. Vishnu Sagar[a], V.G. Gopikrishna[a], G.G. Pandit[b], S.K. Sahu[b], M. Tiwari[b], P.Y. Ajmal[b], V.M. Kannan[a], M. Abdul Shukkur[a], K.P. Krishnan[c]

[a] *School of Environmental Sciences, Mahatma Gandhi University, Kottayam 686560, Kerala, India*
[b] *Environmental Monitoring and Assessment Section, Bhabha Atomic Research Centre, Mumbai, India*
[c] *National Centre for Antarctic and Ocean Research, Goa, India*

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ABSTRACT

The sedimentation rates in Arctic fjords are influenced by the changes in the glacial inputs. The recent studies have indicated the retreat of glaciers due to climate change and subsequent increase in melt water outflow with high content of debris. The debris may contain natural and anthropogenically originated contaminants. The present study analysed the sedimentation rate in inner Kongsfjorden, Ny-Ålesund, Svalbard using $^{210}Pb/^{210}Po$ dating technique. The sedimentation rate ranged between 0.22 and 0.37 cm/year during the last 112 years. The average sedimentation rate obtained was 0.28 cm/y. The rate has been increased during the last 20 years and it might be due to the increased influx of glacial melt water containing debris. Metals and other elements showed an increasing trend towards the surface and observed high deposition rate since 1970s, indicating influence of industrial emissions and it can be a potential threat to Arctic biota.

Global climatic variations and its effects can be easily monitored at polar environments especially in Arctic regions, as it is highly sensitive and worst affected one (Mallorya et al., 2015; Lu et al., 2012). The fjords are vital systems in the Arctic and serve as major points to measure the cause and effect of environmental change. The rate of sediment production and sedimentation in fjords is influenced by glacier front, fjord walls, side streams and other topographical factors (Zaborska et al., 2000; Marek, 2008). Hence there is a high chance of co-deposition of contaminants, which are originated from the industrial emissions and deposited on the ice sheets/glaciers, at the tide water glacier fjords. Therefore the global climate changes and increasing melting may have a significant influence on the deposition of pollutants in the marine ecosystem (Robert, 2000). The present study investigates rate of sedimentation and historic metal contamination close to a glacier front in Kongsfjorden, an Arctic Fjord system at Ny-Alesund, Svalbard.

Kongsfjorden is located in the northwest of Spitsbergen (the largest island in Svalbard archipelago) between 78°52′ and 79°04′ N and 11°20′ and 12°36′E, and is oriented from the southeast to the northwest, with a length of 20 km and a width varying from 4 to 10 km (Svendsen et al., 2002).

Sediment core (28 cm) was collected from Kongsfjorden during the Indian Arctic expedition using Haps corer of 30 cm long. The sample location was very near to tide-water glacier Kronebreen (largest one in Svalbard) and the glacier front is known as Conwaybreen and Kongsbreen (Lat 78.993 and Long 12.3) (Fig. 1). The core was sub sampled at 1 cm interval (a total of 28 samples) and analysed for various parameters.

The age and the activity of core sediment were estimated by alpha spectroscopic method using $^{210}Pb/^{210}Po$ using Constant Rate of Supply (CRS) model (Pandit et al., 2014; Arman, 2006). Geochronological analysis of each samples were performed in at least replicate. Po^{209} and Po^{208} were used as mixed tracer to know the chemical recovery of Po^{210} from sediment samples. Am – Pu source of known activity was used for calibrating the energy and efficiency of alpha spectrometer. Natural uranium source was also used for confirmation of energy calibration. The quality assurance of measurements was assessed through analysis of the Standard Reference Material IAEA-135 Marine Sediment sample. A total number of 17 out of 28 samples were used for the analysis. Sample interval was fine at surface and coarse towards bottom. Mass Accumulation Rate (MAR) (measure of the dry mass accumulating per unit area and time) was also calculated (Clark et al., 1990).

The heavy metals in the core sediment were estimated using ICP-MS (Yuan et al., 2004) after microwave (MARS Xpress, CEM, USA) assisted acid digestion. The concentration of mercury in the core sediment was analysed using Cold vapour atomic fluorescence spectrophotometer

* Corresponding author.
E-mail address: maheshmohan@mgu.ac.in (M. Mohan).

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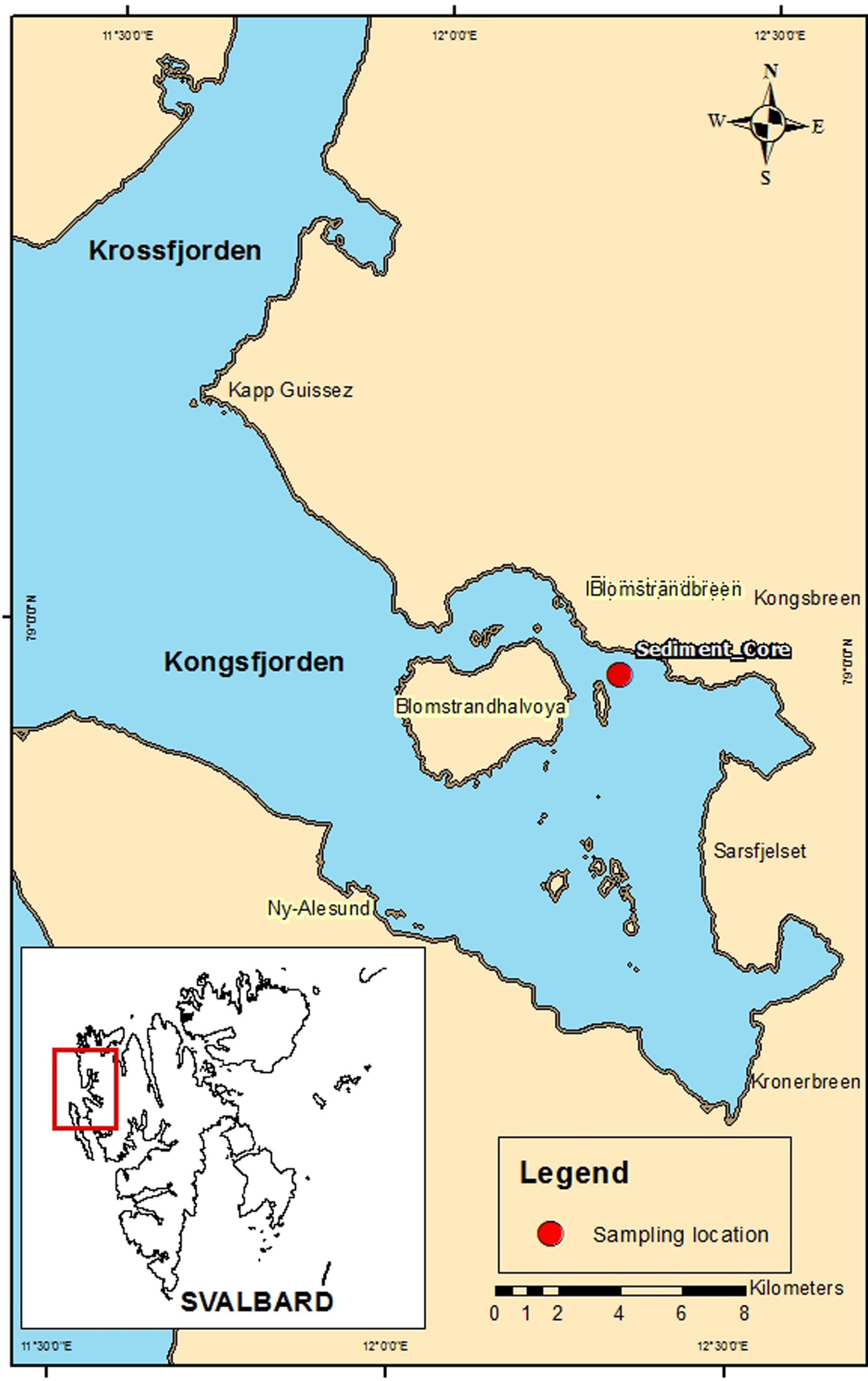

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Fig. 1. Location map showing study area and sampling location.

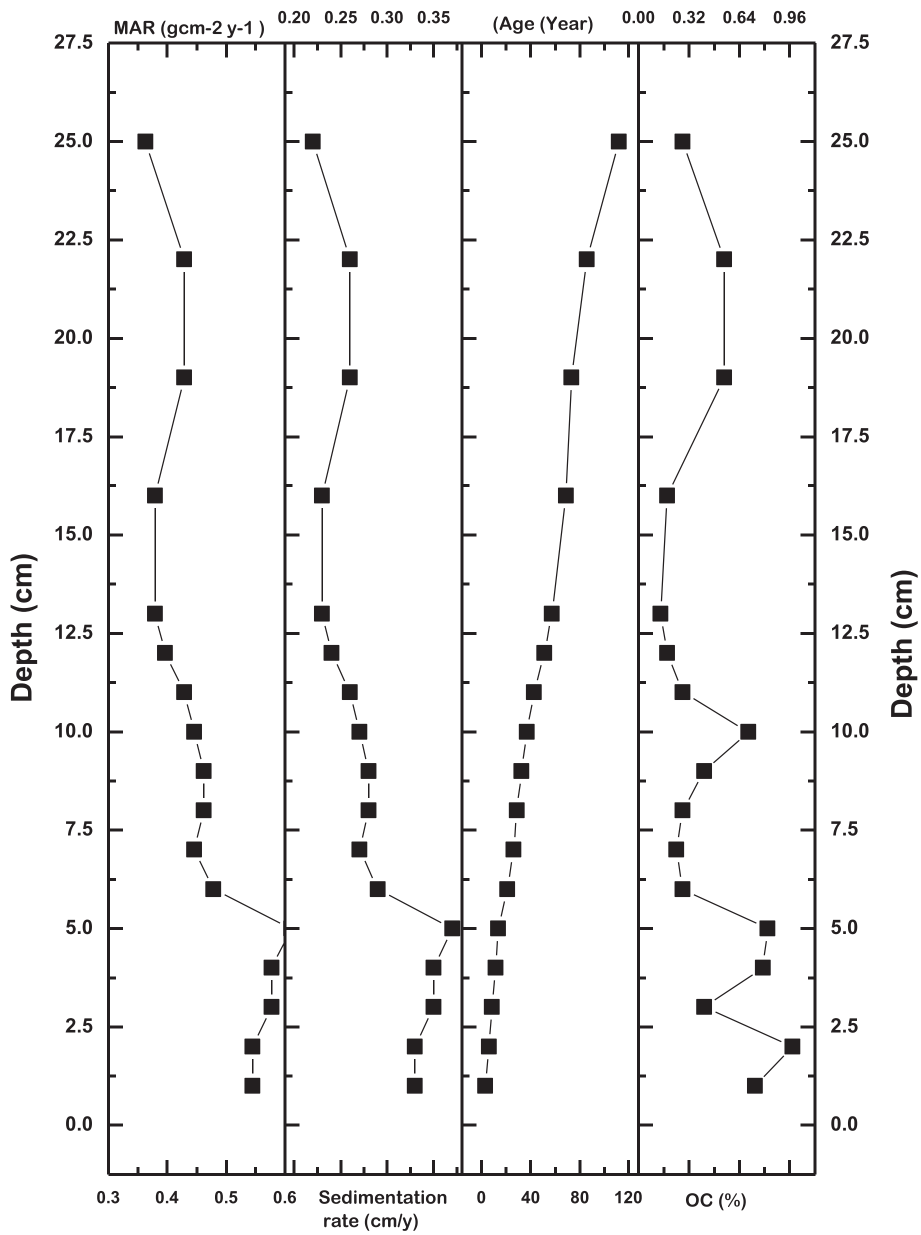

Fig. 2. Sedimentation rate and variation of OC in the core.

(CVAFS, Brooks Rand, USA) after acid digestion and bromine monochloride oxidation as per the USEPA method 1631 (USEPA, 2001). The detection limit of Hg was 0.08 ng/L. The method for total mercury estimation was validated with the certified reference material "Estuarine sediment" (ERMCC 580). The percentage of recovery was 98.07 ± 0.21.

Total ^{210}Pb activity ranged from 13.76 mBq/g to 119.14 mBq/g. The profile of total ^{210}Pb of the core significantly changed with depth. The ^{210}Pb geochronological analysis indicated that the core sediment represent last 112 years, i.e., the core can give details on past environment from the year 1903. The sedimentation rate ranged between 0.22 and 0.37 cm/year with a mean value of 0.28 cm/year (Fig. 2) and is increasing from bottom to surface. Last twenty years (1995 to 2015) has evidenced high sedimentation rate (0.34 cm/year average). The sedimentation rate remains constant around the year 2005 (0.35 cm/year), 1985 (0.28 cm/year) and 1950 (0.23 cm/year).

Mass Accumulation Rate (MAR) was ranged between 0.372 and 0.611 g cm^{-2} y^{-1} with an average of 0.470 g cm^{-2} y^{-1} (SD ± 0.07) (Fig. 2). The maximum and minimum concentration was obtained at a depth of 4–5 cm and 24–25 cm respectively. Barnhart in 2010, got an average MAR of sediment traps at a different distance from glaciers in Kongsfjorden (0.38 ± 0.11 g cm^{-2} y^{-1}, 0.22 ± 0.14 g cm^{-2} y^{-1} and 0.16 ± 0.06 g cm^{-2} y^{-1} respectively). Trusel et al. (2010) found a MAR of 0.95 g cm^{-2} y^{-1} approximately 0.4 km from the ice-marginal delta of Kongsfjorden.

The core sample was taken from the glacier front, which receives melt water with debris from the glaciers. In Kongsfjorden, a change in melting and thus increase in melt water influx occurred during the last one decade (Trusel et al., 2010). The sediment core collected from the glacial front indicates the variation in deposition during this period owing to increasing sedimentation rate and MAR. Hence the present study agrees with other studies, which proved that the sedimentation

Table 1
Comparison of sediment accumulation rate with other studies.

System	Sediment accumulation rate/MAR g cm^{-2} y^{-1}	Sedimentation rate (cm y^{-1})	Reference
Kongsfjorden	0.025	0.5	Zaborska et al. (2000)
Billefjorden	0.1–0.26		Szczuciński et al. (2009)
North West Arctic Alaska	0.34		Naidu et al. (2003)
Kongsfjorden	0.20 (close to glacial margin)		Svendsen et al. (2002)
Kongsfjorden	0.372 to 0.611 (0.470)	0.22–0.37 (0.28)	Present study

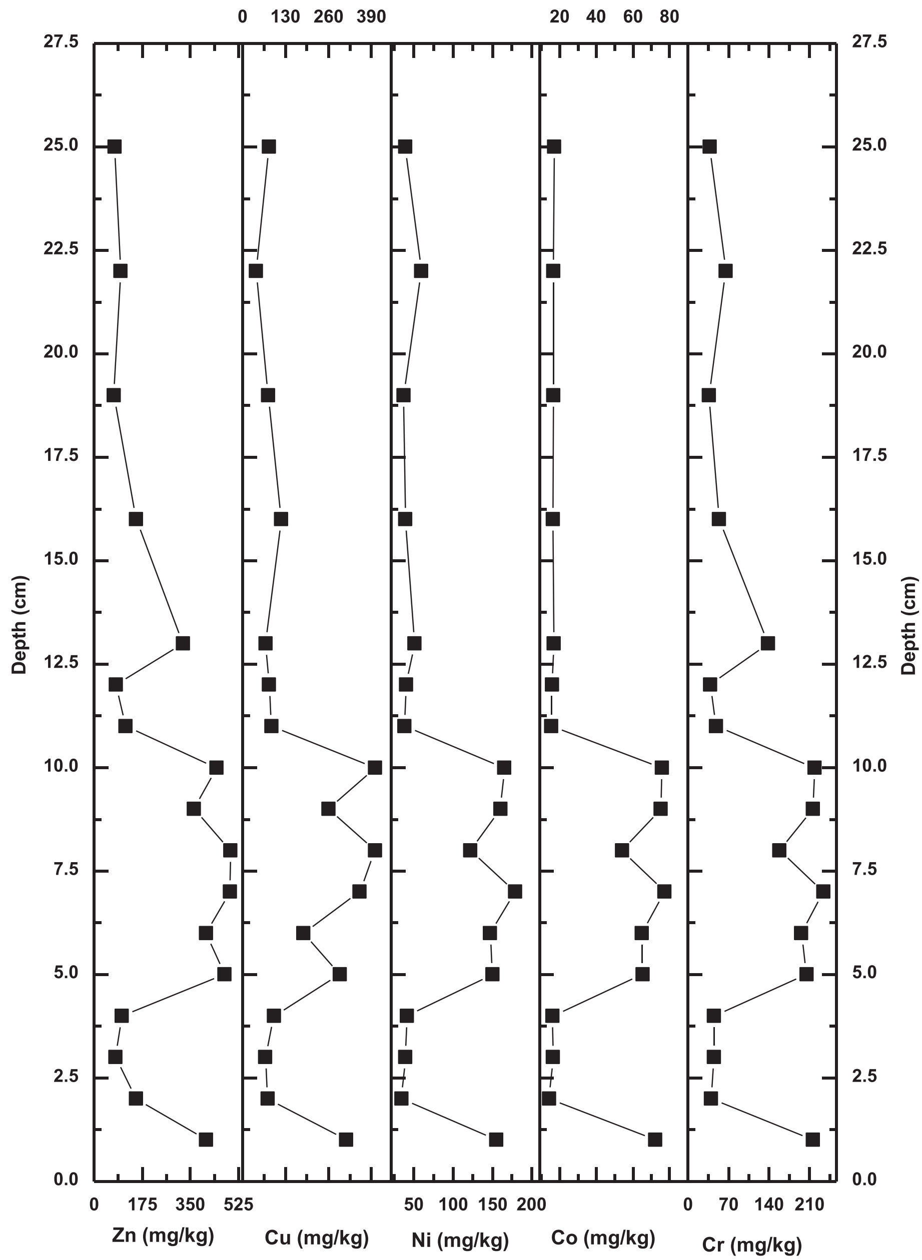

Fig. 3. Metals in the sediment core.

process at the ice front of tide-water glaciers is directly proportional to the volume of melt water (Dowdeswell et al., 1998; Marek, 2008). The results of the present study are compared with earlier studies carried out at Kongsfjorden and other fjords around the globe (Table 1). It indicated a slight increase in sediment accumulation rate compared with the earlier study.

The concentration of Cr in the core was varied from 29.27–234.18 mg kg^{-1} with a mean of 91.13 mg kg^{-1} (Fig. 3). The minimum concentration was observed at a depth of 20–21 cm. The concentration of Co was ranged between 14.091 and 77.24 mg kg^{-1} (Fig. 3) whereas, the concentration of Ni varied from 31.1 to 178.82 mg kg^{-1} (71.71 ± 51.78) (Fig. 3). The concentration of Cu was ranged from 41.27 to 401.75 mg kg^{-1} (Fig. 3). The mean concentration of Zn was 190.62 mg kg^{-1}, whereas the maximum observed was 496.43 mg kg^{-1} (Fig. 3).

The concentration of Al in core sediments was ranged between

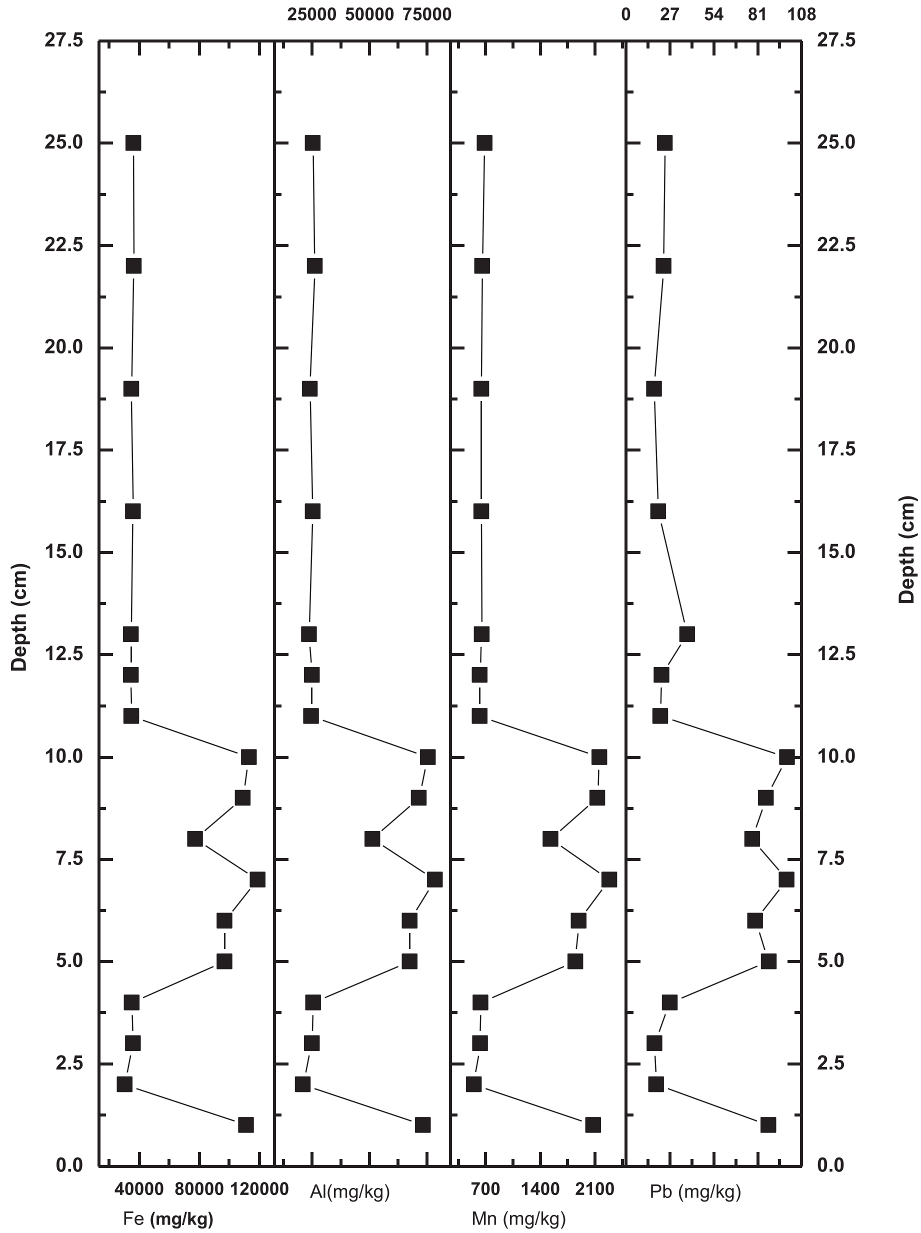

Fig. 4. Metals in the sediment core.

5543.33 and 78,436.79 mg kg^{-1} (35,017.29 ± 21,454.92 mg kg^{-1}), whereas Fe content varied from 30,407.7 to 119,043 mg kg^{-1} (Fig. 4). The mean concentration of Mn was 991.25 mg kg^{-1}. The maximum (2286.71 mg kg^{-1}) and minimum (546. 24 mg kg^{-1}) concentrations were observed at a depth of 6–7 and 20–21 cm respectively (Fig. 4). Pb content in the core sediment varied from 12.33–98.98 mg kg^{-1}, with a mean of 37.89 (Fig. 4).

The concentration of Cd in the core varied from 0.12 to 1.05 mg kg^{-1}(Fig. 5). The concentration of total Hg in the core sediments varied between 0.19 and 0.96 mg kg^{-1}, with a mean value of 0.55 (± 0.24) (Fig. 5). The mercury deposition was highly variable during the past 112 years. This might be due to the influence of local environmental conditions and anthropogenic sources. The increase in concentration towards the surface sediment was observed in the fresh water lakes of Svalbard and low arctic regions (AMAP, 2005 and Shan et al., 2011). High concentration of mercury observed in core sediments from high Arctic regions compared to low Arctic regions. Also the concentration was increasing towards the surface sediment (AMAP, 2005). These reports suggest that the presence of mercury has been increasing during the recent times and the same might have reflected in the depositional pattern.

The increased sedimentation rate also has an influence on the metal accumulation, but it was not very significant (Table 2). Only Cd showed significant relation with sedimentation rate. All the metals are negatively correlated with mercury and positively with each other and it indicated different sources of origin.

The present study revealed that the sediment accumulation rate in the Kongsfjorden is increasing and it indicated that there is an increase in the deglaciation process during the past few decades when high average sedimentation rate observed (0.34 cm/year). This rate can be well supported by the studies done on glacier surface speed and frontal ablation. Kongsbreen has been retreated up to1800m even though the velocity has increased slightly from 1964 to 2012 (Bernard et al., 1994; Schellenberger et al., 2015). Also the frontal ablation has changed from 0.088 Gt a^{-1} (Bernard et al., 1994) to 0.14–0.16 Gt a^{-1} (Schellenberger et al., 2015). The retreat and frontal ablation might have influenced the sediment deposition pattern in the inner part glacial front regions of Kongsfjorden and it reflected in the core taken in the present study also.

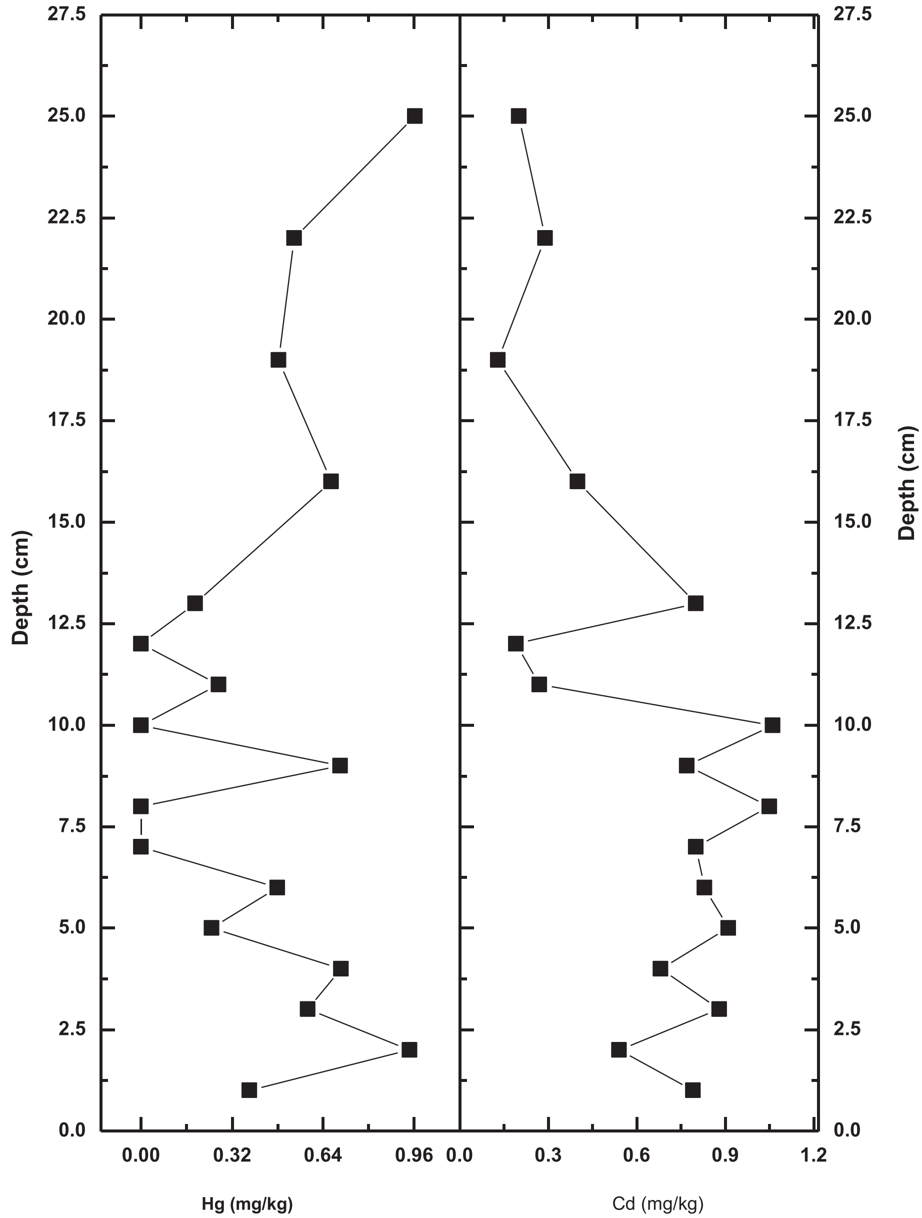

Fig. 5. Metals in the sediment core.

Table 2
Correlation between sedimentation rate, MAR, geochemical parameters and heavy metals in core sediments.

	S. rate	MAR	Cr	Co	Ni	Cu	Zn	Cd	Pb	Mn	Al	Hg
S. rate	1											
MAR	1.00**	1										
Cr	0.190	0.190	1									
Co	0.247	0.246	0.960**	1								
Ni	0.236	0.235	0.971**	0.995**	1							
Cu	0.205	0.204	0.854**	0.904**	0.893**	1						
Zn	0.199	0.198	0.949**	0.899**	0.912**	0.898**	1					
Cd	0.500*	0.494*	0.745**	0.690**	0.694**	0.725**	0.801**	1				
Pb	0.230	0.230	0.977**	0.986**	0.989**	0.926**	0.948**	0.743**	1			
Mn	0.229	0.229	0.959**	0.999**	0.995**	0.895**	0.891**	0.675**	0.984**	1		
Al	0.256	0.255	0.956**	0.997**	0.994**	0.885**	0.883**	0.671**	0.980**	0.998**	1	
Hg	0.134	0.133	−0.478	−0.416	−0.446	−0.555*	−0.548*	−0.363	−0.491*	−0.414	−0.416	1

* Correlation is significant at the 0.05 level (2-tailed).

** Correlation is significant at the 0.01 level (2-tailed).

Hence, the high mass loss from the glaciers might have resulted in for the release of debris embedded within the ice during the last two decades and which might have influenced the sedimentation rate.

All the metals including mercury have showed a sudden increase during 1970s (specifically at a depth of 11 cm) and is extended up to 2000. During this 30 years period comparatively high amount of metal has been deposited in the sediment. There can be a number of factors for this increased deposition of metals. The factors can be (1) any natural disasters like forest fire and volcanic eruption (2) industrial emission from Eurasia (3) release of trapped metals due to increased melting (4) increased local erosion. Even though there is a slight increase in sedimentation rate after 1970s, the last two factors could be neglected as it does not indicate any short term deposition profile. The deposition, what we have observed, lasted for nearly 30 years. The major factors might be the long range transport of metals from natural hazards and industrial emissions. Industrial emissions might have upper hand as the emission was increasing in Europe till 1960s and then showed a decreasing trend (AMAP, 2005). More detailed studies on the sources of contaminants and correlation of different data on melting, glacier retreat, atmospheric inputs and sedimentation may enhance the current knowledge. The increasing trend in sediment metal accumulation will be a potential threat to the health of Arctic biota. The present study conclude that the global climate change has a significant influence on the Arctic glaciers and more detailed studies are necessary to understand the implications of climate change on the Arctic ecosystem.

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